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Technical Lesson 29

AUDIO AMPLIFIER CIRCUITS

Our preceding lesson dealt with a radio receiver employing a single vacuum tube operating as a regenerative detector and, in presenting the fundamental principles governing the actions going on within the circuit, it was pointed out that this tube, by virtue of its detector characteristics, served to demodulate the received radio wave. In other words, the detector separated the audio-frequency currents from the radio-frequency carrier wave that conveyed them through space from transmitter to receiver.

It is very often the case that, although regeneration is used to increase the sensitivity of a receiver, it is impossible to bring in a distant station distinctly and, under certain conditions, the received signals will be weak to the point of being barely audible in spite of the most careful tuning adjustments on the part of the operator. To amplify such weak audio-frequency currents, that is, to increase their strength, a receiver is supplied with one or more additional vacuum tubes and suitable apparatus for operating and coupling the tube circuits together. Any arrangement of apparatus used for increasing the volume of the received audio-frequency signal is known as an audio-frequency amplifier.

TRANSFORMER-COUPLED AUDIO AMPLIFIERS. The audio-frequency amplifier as a whole is composed of a number of vacuum tubes so connected that the signal to be amplified is fed successively from the output (plate) circuit of the first tube to the input (grid) circuit of the next following tube and so on through as many stages as are necessary to realize the desired amount of volume. Each tube contributes its share to the total amplification obtainable from the amplifier as a whole. This procedure of passing the signal successively through a number of amplifying tubes is known as a "cascade" connection.

More specifically, the signal to be amplified is impressed upon the grid of the first tube of the amplifier and due to the amplifying ability of the tube the signal reappears in the tube's plate circuit greatly increased in strength. The signal is then transferred from the plate circuit of this tube to the grid circuit of the next following tube where the same action is repeated and the signal, therefore, is still further amplified. This procedure is repeated in as many stages of amplification as may be necessary for building up the strength of the signal to the desired level as we just explained.

In order that the signal can be transferred from the plate circuit of one tube to the grid circuit of the next following tube, some sort of device or unit must be used to effect this transfer of signal energy. Such a device takes a variety of forms, but whatever it may be, just so long as the part performs this function of coupling the plate circuit of one tube to the grid

circuit of the next following tube, it will be termed in general an inter-tube coupler or interstage coupler.

The three principal types of devices used as intertube couplers are resistors, impedances (in the form of choke coils), and transformers. Furthermore, audio-frequency amplifiers are generally classified according to the type of intertube coupling employed, namely:

- (A) Resistance-coupled amplifiers.
- (B) Impedance-coupled amplifiers.
- (C) Transformer-coupled amplifiers.

Of these three types, the transformer-coupled amplifier is the most widely used and is the type of amplifier with which we shall deal in this lesson. Each stage of amplification is composed essentially of a vacuum tube, an intertube coupler (in this instance a transformer), and other incidental apparatus such as the tube socket and filament rheostat and batteries.

An audio-frequency amplifier may incorporate as many stages as desired, but the number of stages usually employed rarely exceeds three. There are broadcast receivers manufactured which incorporate four stages of audio-frequency amplification, but such receivers are very few in number. The great majority of broadcast receivers employ two stages of amplification, or at the most, three stages of amplification, the latter being sufficient to deliver as much signal volume as ordinarily required.

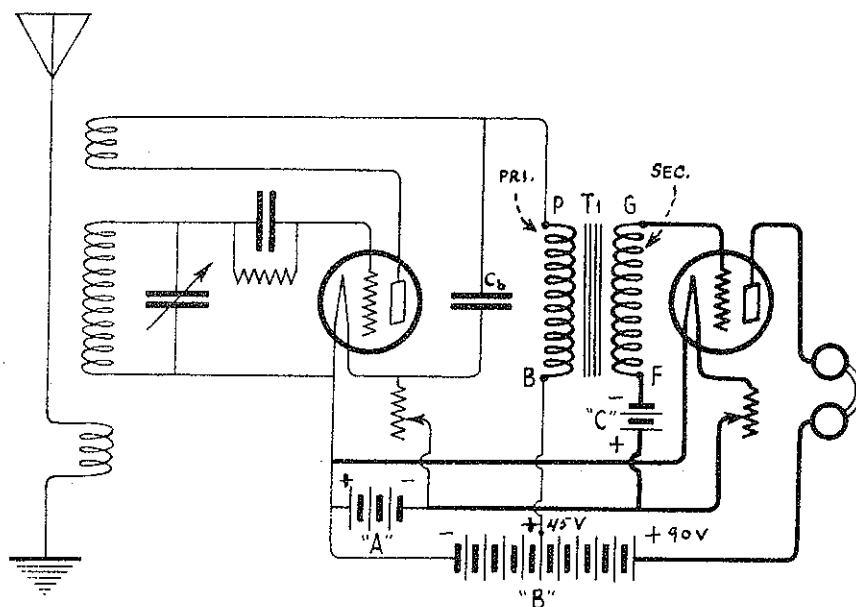


Figure 1

In Figure 1 is shown the schematic wiring diagram of a single stage of audio-frequency amplification connected to the receiver which was described in the preceding lesson. As shown in this diagram, the primary of the audio-frequency amplifying transformer T1 has been substituted for the headphones in the plate circuit of the detector tube. The secondary terminals G and F of this

transformer are connected to the input terminals of the amplifier tube, that is, to its grid and negative filament terminals. This transformer T1 is one having a closed iron core upon which is mounted a primary and a secondary winding — the whole assembly being enclosed in a thin sheet-iron casing which serves to protect the windings from damage and, also, to prevent the escape of stray magnetic fields due to magnetic leakage in the transformer core and coils. The principle of operation is briefly that energy is transferred from primary to secondary windings by virtue of ordinary transformer action as described in our early lessons dealing with electromagnetic induction.

More specifically, the plate current of the detector tube possesses an alternating-current component of audio frequency. As this alternating current continually varies according to the characteristics of the signal and flows through the transformer primary it induces fluctuating voltages of similar characteristics in the secondary. Since the secondary terminals are connected to the input terminals of the amplifier tube socket these voltages induced in the secondary will be impressed between the grid and filament of the tube. Thus, the signal energy present in the plate (output) circuit of the detector tube is transferred to the grid (input) circuit of the amplifier tube by means of transformer coupling.

TRANSFORMER TURNS RATIO AND SECONDARY INDUCED VOLTAGES. At this point, let us again stress a fact that already has been covered in a preceding lesson. Any vacuum tube is a voltage operated device, that is, the greater the fluctuation in the voltage impressed upon the grid of the tube, the greater will be the corresponding fluctuation in its plate current. This being the case, it is easy to appreciate that the higher the voltages developed in the secondary of the transformer the greater will be the response obtained from the amplifier tube to whose grid this secondary is connected. Furthermore, the voltages developed in the transformer secondary will depend principally upon the turns ratio of the device, and if the transformer possesses a step-up ratio the secondary voltages will be raised to some value higher than the primary voltages. Following the same line of thought, it would appear to be very much to our advantage to always use amplifying transformers having a high turns ratio and in this way obtain high voltage amplification. A high step-up ratio transformer would be necessary if we were concerned only with the production of great signal strength, but this is not the case as we will explain.

Audio amplification in broadcast reception must also be considered from the standpoint of the quality of reproduction. In broadcast reception it is of prime importance to obtain natural, life-like reproduction and the desirability to obtain a great volume of signal is a secondary consideration. In order to obtain good quality of reproduction it is essential that the transformer amplify equally well at all frequencies in the audio range which includes frequencies between approximately 30 and 5000 cycles. Should the transformer accentuate certain frequencies, that is, over-amplify them and discriminate against others, then it is said that the transformer distorts those audio frequencies. In order to obtain faithful reproduction this distortion must be kept as low as possible — the degree of absence of distortion being the customary way by which the worth of the amplifier is judged.

Because of a number of practical considerations in transformer design it is highly impracticable to produce an audio-frequency amplifying transformer capable of distortionless amplification and at the same time having a high

turns ratio. The limit of the turns ratio whereby faithful amplification will result is about five to one (5:1), but the audio-frequency amplifying transformers usually employed have a turns ratio of about three to one (3:1), or three and one-half to one ($3\frac{1}{2}$:1).

CURVES ARE USED TO INDICATE THE PERFORMANCE OF AUDIO TRANSFORMERS. Curve B in Figure 2 is the amplification curve of a good low-ratio transformer. A curve of this kind is a visual means of showing the performance of a particular transformer throughout the audio-frequency range. Observe that all frequencies between approximately 100 and 5000 cycles are amplified equally well while there is but a slight decrease in amplification at the lower range of frequencies between approximately 100 and 30 cycles. An amplifier employing one or more transformers that would give an amplification curve similar to curve B in Figure 2 is capable of providing faithful and pleasing reproduction due to the almost complete absence of distortion.

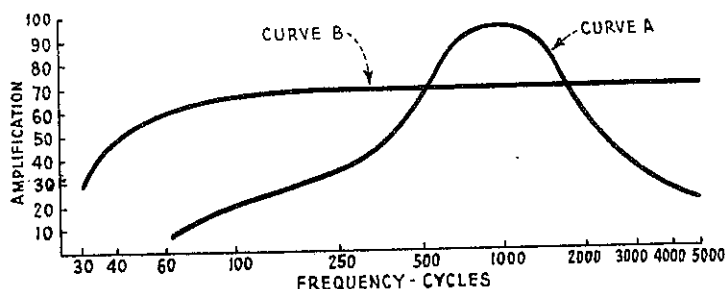


Figure 2

Curve A is the amplification curve of a typical high-ratio transformer having a turns ratio of ten to one (10:1). Compare curve A with curve B and note the irregularities in curve A as compared to the smooth, flat curve B. Note that the two curves, A and B, representing the characteristics of two different transformers operating under similar conditions are plotted on the same chart, Figure 2, in order to easily compare them. Such an irregular curve as A indicates that the transformer from which it was plotted is incapable of amplifying any current whose frequency is below 70 cycles. On the other hand, any current having a frequency in the neighborhood of 1000 cycles is over amplified out of all proportion to other frequencies. An amplifier employing a transformer that would give a curve like curve A would prove unsatisfactory since it would deliver a highly distorted reproduction of voice and music. Hence, there would be an almost complete absence of the low frequencies (bass notes) so necessary to the full enjoyment of good music, while the tendency of the transformer to over amplify certain of the high frequencies would cause an undesirable sound, which is called blasting, to be emitted by the phones or loudspeaker when notes or overtones of corresponding frequencies were received. In brief, if an amplifier incorporates a transformer which is not carefully selected for the use to which it will be subjected then it is very likely that the reproduction of speech will sound indistinct and "mushy," whereas, music will be more or less harsh.

It might be well to point out that any audio amplifier when completed can be used with any kind of a radio receiver by simply connecting it in the proper manner to the output of the detector. An audio amplifier, of whatever type

it may be, is in itself a complete unit that can be dealt with apart from the actual radio-frequency or tuning circuits or detector portions of a receiver.

The instruments comprising a typical audio-frequency amplifier are shown on a panel and baseboard in Figure 3. We have illustrated the arrangement of parts in this manner to make it easy for you to study the circuits and to facilitate our explanation later as to how a circuit consisting of only one stage of a-f amplification may be altered to incorporate a second stage of a-f amplification.

The first step in studying about a detector and an a-f amplifier is to examine the picture diagram in Figure 3. There it will be seen that the audio-frequency amplifying transformers T1 and T2 are in the positions indicated so that their terminals will be conveniently located with regard to the terminals of other parts, such as the vacuum tube sockets. Each audio-frequency amplifying transformer has two primary terminals, P and B, and two secondary terminals, G and F; these identifying letters are the usual letters found stamped into the metal case of the transformer beneath its respective terminals. Notice that the detector and a-f amplifier tubes are each supplied with individual rheostats to provide regulation of filament voltage.

The schematic diagram of Figure 1 may be followed throughout our explanation, of if you refer to the picture diagram of Figure 3, providing you disregard the connections shown in dotted lines. The dotted connections in Figure 3 are those required for the addition of a second stage of amplification which would be attached immediately following the first stage of amplification.

Let us now follow out the continuity of the various circuits and find out how they are related. From the +A binding post on the terminal strip note that there is a connection to the corresponding + filament terminal on the tube socket. The other - filament terminal is connected to one of the terminals of the rheostat on the panel. The remaining rheostat terminal connects to the -A binding post on the terminal strip. This places the rheostat in the negative filament line. In this circuit a storage battery or "A" battery would be used to supply filament voltage to all tubes.

The only difference between the radio receiver already explained in the preceding lesson and this one is that the primary of the audio-frequency amplifying transformer is substituted for the headphones in the plate circuit of the detector tube. You can easily see how this might be done by tracing the wire which leads from the tickler coil to one of the tip jacks. Notice that this wire is disconnected from the tip jack and connects to the P terminal of the audio-frequency transformer. The wire which connects the Det +B terminal to the other tip jack is removed from the tip jack and it connects instead to the B terminal of the audio-frequency transformer. One terminal of the bypass condenser C_b connects to the negative side of the filament circuit as before while its remaining terminal connects to the lead running from the tickler coil to the P terminal of the transformer. A wire connection is shown on the diagram between the G terminal of the transformer and the G (grid) terminal of the amplifier tube socket and, also, there is another connection between the F terminal of the transformer and the C- binding post on the terminal strip. The two binding posts marked C+ and A- connect to each other and, also, the P (plate) terminal of the amplifier tube socket connects to one of the tip jacks, and the other tip jack connects in turn to the Amp B+ binding post on the terminal strip.

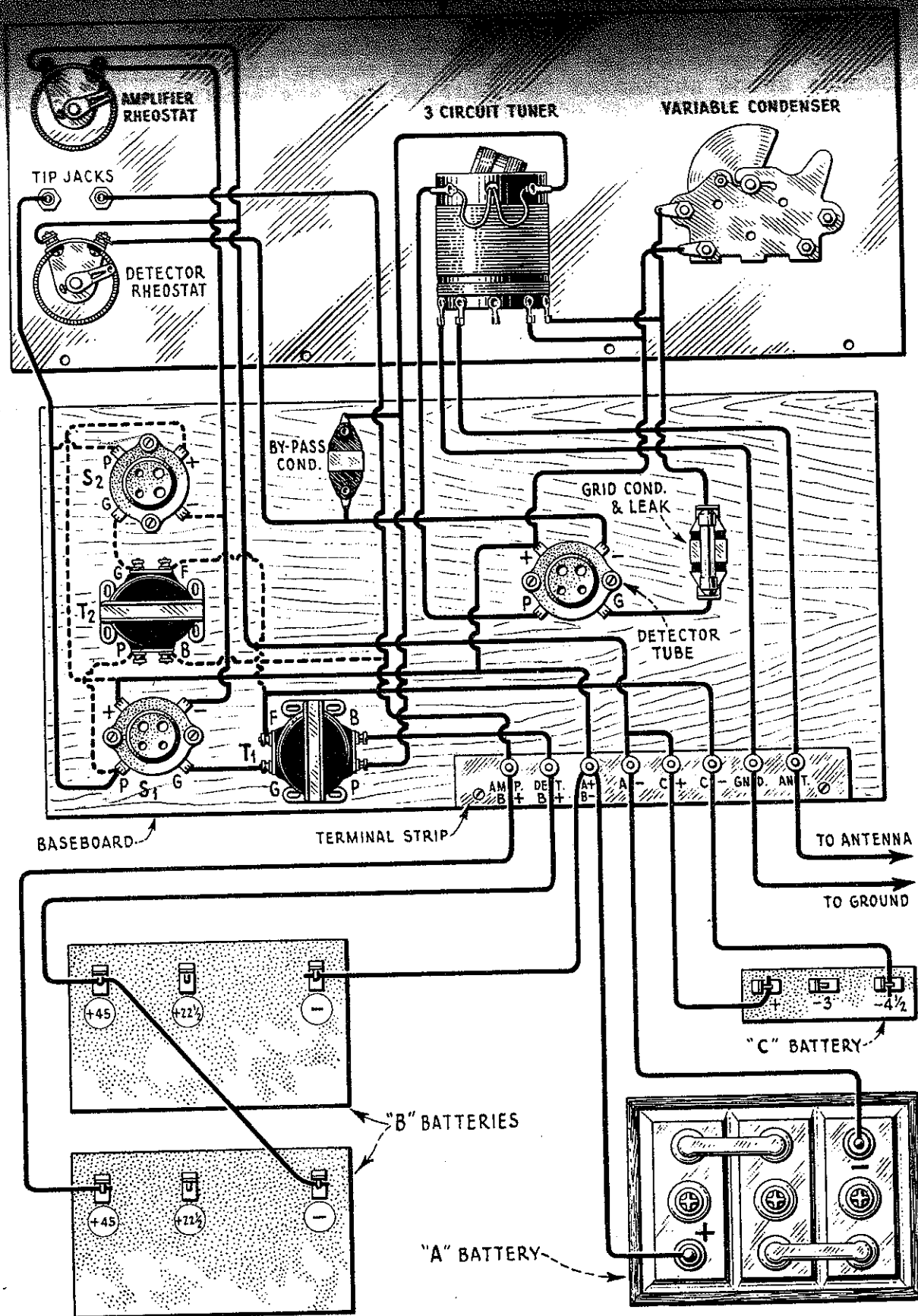


Figure 3

This completes the wiring arrangement of the receiver. A circuit of this kind is placed in operation by plugging the phone cord tips into the tip-jacks after having first connected the proper batteries to the receiver. In the picture diagram in Figure 3 there are two 45 volt "B" batteries shown connected to the receiver in such manner as to apply 45 volts to the plate of the detector tube and 90 volts to the plate of the amplifier tube. A $4\frac{1}{2}$ volt "C" battery, connected as shown, furnishes the correct amount of grid biasing potential to the grid of the amplifier tube. These are the values of voltages recommended for use with such a circuit. However, if only one 45 volt "B" battery were to be used it would be connected to the B- and Det+B binding posts. By the use of a wire jumper between the Det+B and Amp+B binding posts, the voltage of this "B" battery will be applied to the plates of both the detector and amplifier tubes. In the event that only 45 volts were applied to the plate of the amplifier tube a "C" battery would not be required and, therefore, in this case, the "C" battery would have to be disconnected from its binding posts, C+ and C-. Now then, since disconnecting this "C" battery would open the grid circuit of the amplifier tube it would be necessary in order to close this circuit to connect a wire jumper between the binding posts C+ and C-.

USE OF A RADIO-FREQUENCY BY-PASS CONDENSER IN THE DETECTOR PLATE CIRCUIT. The condenser C_b in Figure 1 in this lesson functions in the same manner as condenser C_b in Figure 1 in Lesson 28, inasmuch as both serve to by-pass the radio-frequency component of the detector plate current around the high inductive reactance of the transformer primary. However, in practice it is well known that in some instances a receiver of this kind will continue to operate satisfactorily with the by-pass condenser disconnected. This is accountable due to the distributed capacity of the primary winding. Distributed capacity effect is an inherent characteristic of any coil and is caused by adjacent turns of wire acting in a manner similar to the plates of tiny condensers whenever current flows through the turns. Although this condenser action between any two turns in a coil is extremely small, yet the total distributed capacity of a coil may be large since capacity effects are additive, that is to say, the total effect is the sum of these small individual adjacent turn capacities. Inasmuch as the primary winding of any audio transformer is composed of hundreds of turns of wire, the total distributed capacity of such a winding often reaches an appreciable value. The effect of the distributed capacity of a large winding is to form a shunt condenser across the winding exactly as would an actual condenser if it were connected across the winding. It will be observed that we have an actual condenser, the one marked C_b in Figure 1 connected across the transformer primary winding. If the value of the distributed capacity of the primary winding approximated that of condenser C_b it would be found that condenser C_b would not then be absolutely necessary to the proper operation of the circuit and, therefore, it could be eliminated.

Now, considering this matter from a practical viewpoint, the value of the distributed capacity of a winding cannot be depended upon for it is apt to vary in different transformers. Furthermore, the distributed capacity may not only differ in the products of different manufacturers, but it may prove to be a variable quantity in transformers of the same make. Hence, to eliminate this element of uncertainty and insure the proper functioning of a receiver, a by-pass condenser of sufficient value to meet the requirements is most generally connected in the manner similar to condenser C_b as indicated in Figure 1. To summarize the foregoing it can be said that when comparing a simple receiver with an audio amplifier there will be an appreciable

increase in the strength of received signals due to the use of the stage of audio-frequency amplification.

A TWO-STAGE AUDIO AMPLIFIER. Having explained the essential features of a single stage of a-f amplification in the receiver, let us now proceed with the addition of a second stage. This second a-f stage will function according to the same principles as outlined for the first a-f stage.

In regard to the alterations of the circuit in Figure 1 that would be necessary to provide a 2nd a-f stage refer to Figure 3. Notice that the 2nd a-f transformer, T2 in Figure 3, would be located to provide a convenient placement of its terminals in relation to the terminals of other parts as indicated. The tube socket which holds the second amplifier tube is marked S2.

The complete schematic wiring diagram of the regenerative detector, 1st and 2nd stage audio amplifier with transformer coupling is shown in Figure 4. If you wish to compare the picture diagram of Figure 3 which shows the actual arrangement of parts in a typical circuit of this kind with the schematic diagram of Figure 4 be sure to take particular notice of the wiring drawn in dotted lines.

Keep in mind that the purpose of the diagram in Figure 3 is primarily to show the relative positions of instruments and wiring in the typical circuit which we are describing and the dotted lines indicate the necessary changes in wiring for the addition of a second audio stage. The following paragraphs explain how the circuit in Figure 1 would be altered for attaching a second stage of audio amplification.

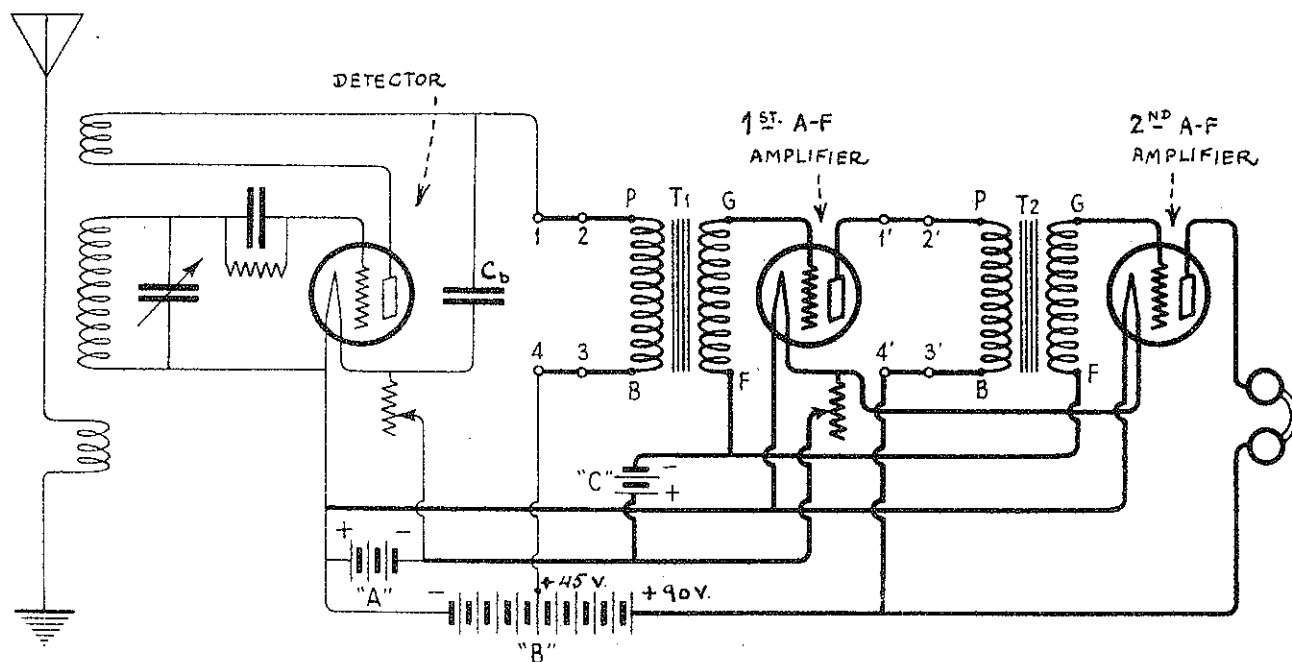


Figure 4

Observe that the + filament terminal of S1 socket connects to the + filament terminal of socket S1 while the - filament terminal of socket S2 connects to the corresponding - filament terminal of S1. In this manner the filaments of both amplifier tubes are connected in parallel and the filament rheostat, being in series with these filaments; serves to control the filament current

which heats these filaments. The necessary changes consist of disconnecting one end of a lead which runs from the plate terminal of socket S1 to a tip jack. The end of the lead that would be disconnected from the tip jack would then be connected instead to the P terminal of transformer T2. Another wire which connects the Amp +B binding post to the other tip jack would be disconnected from this tip jack and in turn would be connected to terminal B on the a-f transformer T2. The G terminal of transformer T2 connects to the G (grid) terminal of socket S2, and the F terminal of transformer T2 connects to the binding post C—on the terminal strip. The P (plate) terminal of socket S2 connects to one of the tip jacks while the remaining tip jack connects to binding post Amp +B on the terminal strip. This completes the changes that would be required for the addition of a second stage.

The batteries connect to the receiver as previously indicated in Figure 3, the same "C" and "B" batteries serving to supply plate and grid biasing potentials respectively to both amplifier tubes. Just as in the case with only a single stage of audio amplification using a plate potential of 90 volts, it would require a $4\frac{1}{2}$ volt "C" battery to supply the requisite grid bias potential for two stages, providing both stages employed the same type of tube and the same plate potentials. If, however, a plate potential of only 45 volts were to be used on the amplifier tubes, the "C" battery could be omitted and, as we previously explained, the "C" battery binding posts would then have to be bridged with a wire jumper to close this circuit.

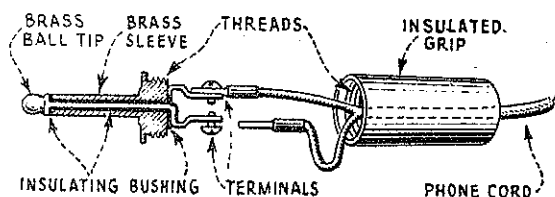


Figure 5

THE USE OF JACKS AND PLUGS. In practical reception there are occasions when an operator may wish to listen to a signal either directly as it comes from a detector or after the signal has been intensified through one or more stages of amplification. This can be easily accomplished by the proper use of "jacks" and "plugs" inserted in the plate circuit of the detector tube, the first amplifier tube and the second amplifier tube. This permits the operator to connect the headphones into the plate circuit of either the detector tube, first amplifier tube or second amplifier tube without the necessity of making changes in the wiring of the amplifier. In other words, when such devices as jacks are incorporated in an audio amplifier the operator can easily and quickly connect the headphones into the plate circuit of any one of the tubes in the amplifier, and in this way use the output of the detector when listening to strong signals, or the output of one stage of audio amplification if the signals are moderate in strength, or providing the signals are weak then the output of both stages of amplification can be used to boost the signal.

The conventional type plug, shown in the sketch in Figure 5, consists essentially of a brass sleeve, a brass ball-tip and an insulated grip or handle. The sleeve and ball-tip each terminate in a connector within the grip and both are thoroughly insulated from each other by means of a bushing made of insulating material such as hard rubber, bakelite, or fibre. The headphone cord

is passed through the hole in the end of the handle and the cord tips are clamped beneath the terminal screws which make connection to the ball-tip and sleeve respectively. The grip is then screwed to the plug proper by means of a thread arrangement provided for this purpose.

In Figure 6 is shown a side view of a "double-circuit" jack. The construction is simple and the drawing is self-explanatory. There are four metal leaves made of spring brass or steel in this type of jack and each leaf is provided with a small contact lug for making soldered connections. The jack operates as follows: When there is no plug inserted in the jack the two upper leaves and the two lower leaves are in contact with each other as shown. However, when the plug is inserted in the jack, as shown in Figure 7, the uppermost leaf is pushed away from the leaf immediately beneath it, thus breaking the contact between these two leaves, but leaving the uppermost leaf in contact with the sleeve of the jack. At the same time, the ball-tip of the jack pushes the lowest leaf away from the leaf immediately above it, thus breaking the contact between them, but leaving the lowest leaf in contact with the tip of the plug. A jack is used in the plate circuit of each tube.

The receiver shown in Figure 4 will require the use of three jacks if it is desired to plug the headphones into the plate circuit of any one of the three tubes. Observe that a double-circuit jack must be used in the plate circuits of both the detector and first amplifier tube. However, a single-circuit jack similar to the one in Figure 8, must be used in the plate circuit of the last amplifier tube. Just where all of the "double-circuit" and "single-circuit" jacks are located in the various plate circuits is illustrated in Figure 9.

Phone jacks are usually mounted upon the panel of a set in the manner shown in Figures 7 and 8. Note that a hole of proper size must first be made in the panel to support the jack and after mounting it is held securely in place by a nut.

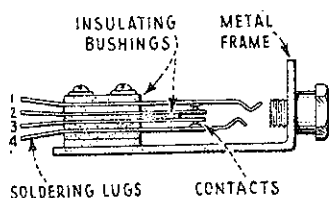


Figure 6

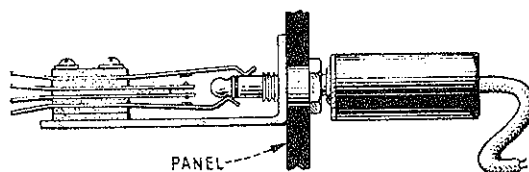


Figure 7

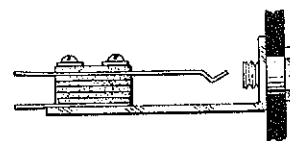


Figure 8

HOW A JACK FUNCTIONS IN A PLATE CIRCUIT OF A TUBE. A double-circuit jack is connected in the detector plate circuit by breaking the circuit between points 1 and 2, and between points 3 and 4 as indicated in Figure 4. The circuit is then completed by a wire which connects from point 1 to leaf No. 1 of the jack, and by another wire which connects leaf No. 2 to point 2. Leaves 3 and 4 are connected to wires 3 and 4 respectively. With these changes the jack is properly connected to the plate circuit.

When no plug is inserted in the jack, leaves 1 and 2 are in contact with each other and thus the plate of the detector tube is connected to the P terminal of the amplifying transformer. Also, springs 3 and 4 make contact with each other thus closing the circuit between the B terminal of the transformer and the +B battery lead.

Upon inserting the plug in the jack, leaves 1 and 2 are forced apart, thus breaking the connection between the plate of the tube and the transformer. Similarly, leaf 4 is forced away from leaf 3 thus breaking the connection between the transformer and the "B" battery lead. However, in this case, leaves 1 and 4 are in contact with the sleeve and tip of the plug respectively and, thus, the circuit is completed from the plate of the tube through the headphones to the "B" battery.

From the foregoing it can readily be seen that when the plug is inserted in the jack the transformer primary is disconnected from the plate circuit and the headphones are automatically substituted for it and, hence, the audio-frequency current in the plate circuit of the detector tube will flow through the headphones and not through the transformer. However, when the plug is withdrawn from the jack, leaves 1 and 2 and leaves 3 and 4 spring together thus reconnecting the transformer primary into the circuit of the detector tube and this time the audio-frequency current in the detector plate circuit is forced to flow through the transformer primary. After the audio current which conveys the signal acts on the transformer secondary by electromagnetic induction then this signal energy passes to the audio amplifier and its volume is increased in the usual manner.

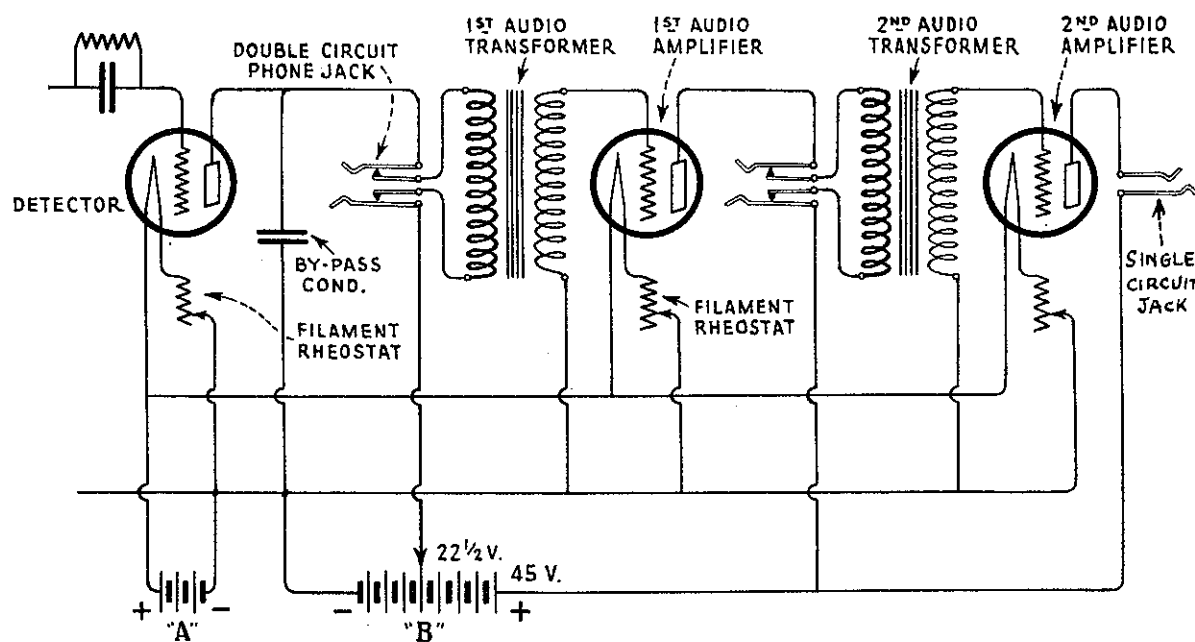


Figure 9

The same principles are applied for the use of another double-circuit jack in the plate circuit of the first audio amplifier as in the case of the jack in the detector plate circuit. The plate circuit of the first amplifier tube is opened between points 1' and 2' and between points 3' and 4' as indicated in Figure 4. Note that 1' connects to leaf No. 1, and 2' to leaf No. 2, and 3' to leaf No. 3, and 4' to leaf No. 4. The insertion or withdrawal of the plug results in the same automatic switching of the connections as in the detector jack, that is, from transformer to phones and vice versa. Figure 9 illustrates the use of single circuit and double circuit jacks.

A single-circuit jack, a side view of which is shown in Figure 8, is used in the plate circuit of the second audio-amplifier tube. The connection of the headphones into the plate circuit of this tube is effected by contact between the tip of the plug and the leaf of the jack, and by contact between the sleeve of the plug and the metal frame of the jack. The use of a double-circuit jack in the plate circuit of this tube is unnecessary as the jack is not required to automatically change the plate connections from transformer primary to phones, or from phones to transformer primary as it must do in the detector and first audio stage. To change the connections would be a simple matter. It could be done by disconnecting the plate and +B battery leads from the tip-jacks and by connecting these leads to the leaf and frame of the single-circuit jack.

When headphones are connected in the output of a two-stage a-f amplifier very strong signals are usually received when listening-in to nearby stations. At no time should the signals in the headphones be so loud that the phones would have to be removed from the ears. If the signals from a certain transmitter were to come in so strong as to cause the volume of signal to be too great for comfort, reduce the signal strength to the proper level by lowering the filament current supplied to the amplifying tubes by adjustment of the rheostat.

A very strong signal should never be permitted to act on the phones for any length of time because it might result in making the phones "rattly" and less sensitive to weaker signals, or it might possibly damage the phones completely.

EXAMINATION - LESSON 29

1. What is the purpose of the audio-frequency amplifying transformer?
2. State the purpose of the detector plate by-pass condenser.
3. How many stages of audio-frequency amplification are usually employed?
4. Name the principal types of coupling devices employed in an audio amplifier.
5. Why are jacks used?
6. Will a high-ratio transformer give distortionless amplification?
7. Which is more important in an audio-frequency amplifier used in broadcast reception — volume or quality?
8. What is the usual turns ratio of a good transformer capable of faithful amplification?
9. (a) What would be the advantage of using high-ratio transformers?
(b) What would be the disadvantage?
10. Explain the operation of a double-circuit jack.